6. Land-Use Issues

Overview

Land-use and forestry issues are important to national and global inventories of greenhouse gases in three ways:

- Vegetation can "sequester" or remove carbon dioxide from the atmosphere and store it for potentially long periods in above- and below-ground biomass, as well as in soils. Soils, trees, crops, and other vegetation may make significant contributions to reducing net greenhouse gas emissions by serving as carbon "sinks."
- Harvested wood put into wood products, or eventually into landfills, can potentially sequester carbon dioxide from the atmosphere for decades before the carbon stored in the wood products decays and is released to the atmosphere.
- Human-induced land-use changes and forest management practices can alter the quantities of atmospheric and terrestrial carbon stocks, as well as the natural carbon flux among biomass, soils, and the atmosphere.[108]

Land-use issues are of particular interest to U.S. policymakers, because U.S. forests and soils annually sequester large amounts of carbon dioxide. Much of the forest land in the United States was originally cleared for agriculture, lumber, or fuel in the hundred years before 1920. Since then, however, much of the agricultural and pasture land has reverted to forest land, increasing its ability to sequester atmospheric carbon dioxide.

The amount of carbon being sequestered annually is uncertain, in part because of an absence of data and difficulties in measuring carbon sequestration. Moreover, in addition to technical uncertainties, there are also policy and accounting questions about the aspects of the carbon cycle that should be included in national inventories as anthropogenic emissions and removals. Further, recent studies have indicated the possibility that vegetation may also be a source of methane (see box on page 73).

The 1996 revised guidelines for national emissions inventories, published in 1997 by the Intergovernmental Panel on Climate Change (IPCC), include methods for calculating carbon sequestration and net carbon dioxide flux to the atmosphere resulting from land-use changes and land-use activities, such as forestry.[109] The IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry*[110] (LULUCF GPG), published in 2003, complements the 1996 IPCC guidelines. The U.S. Environmental Protection Agency (EPA) estimates annual U.S. carbon sequestration in 2004, based on data generated by the U.S. Department of Agriculture (USDA), at 780.1 million metric tons carbon dioxide equivalent ($MMTCO_2e$), a decline of approximately 14 percent from the 910.4 $MMTCO_2e$ sequestered in 1990[111] (Table 33). Land use, land-use change, and forestry (LULUCF) practices offset 11 percent of total U.S. greenhouse gas emissions in 2004 and 15 percent in 1990.[112] In terms of anthropogenic carbon dioxide emissions, U.S. LULUCF practices offset 13 percent of U.S. carbon dioxide emissions in 2004, as compared with 18 percent in 1990.

Land-Use Change and Forestry Categories

The EPA, following LULUCF GPG, reported 2004 data on carbon fluxes according to the following categories: forest land remaining forest land, cropland remaining cropland, land converted to cropland, grassland remaining grassland, land converted to grassland, and settlements remaining settlements. Data constraints

[108] The net numerical difference, or "flux," between carbon sequestration and carbon release due to natural factors can be viewed as a measure of the relative contribution of biomass to the carbon cycle.

[109] Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories,* Vol. 3 (Paris, France, 1997), web site www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

[110] Intergovernmental Panel on Climate Change, *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (Hayama, Japan, 2003), web site www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm. The EPA has been using the LULUCF GPG as well as the 1996 guidelines since its 1990-2003 inventory.

[111] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2006.html.

[112] EIA does not include sequestration from land-use change and forestry as part of its annual estimate of emissions of greenhouse gases in the United States. Note that land use refers to maintaining land within a particular category of use, such as forests remaining forests, whereas land-use change refers to changing from one land-use type to another, as when forest is converted to grassland, or wetlands are drained to create more land for agriculture.

prevented the EPA from reporting on all the LULUCF GPG categories for land use and land-use change.

Forest Land Remaining Forest Land

The values for forest carbon dioxide fluxes reported for this category are based on estimates of changes in forest carbon stocks. The components analyzed are above-ground biomass, below-ground biomass, dead wood, litter, soil organic carbon, harvested wood products in use, and harvested wood products in landfills. The estimated carbon flux (including all carbon-based greenhouse gases) from each of these components—except for soil organic carbon—was calculated using the USDA Forest Inventory and Analysis (FIA) database (FIADB) and methodologies consistent with the LULUCF GPG and the Revised 1996 IPCC Guidelines.[113] The FIADB is based on State surveys carried out at intervals of 5 to 14 years; accordingly, adjustments were made for temporal and spatial gaps, using FIA's recently introduced national plot design and annualized sampling.[114] Estimation of the average density of soil organic carbon (carbon per unit area) was based on USDA's State Soil Geographic (STATSGO) data and FIA survey data (areas of broad forest type).[115]

Nitrous oxide emissions from fertilized forest soils were calculated by using a default methodology consistent with the LULUCF GPG. Pine trees, being the dominant species planted for timber in the southeastern United States, were taken as representative of fertilized forests in the country, and the average reported fertilization rate of 150 pounds of nitrogen per acre was multiplied by the area of pine forest receiving fertilizer.

Cropland Remaining Cropland

Estimates of carbon stock changes from this category include changes in agricultural soil carbon stocks involving both mineral and organic soils on cropland remaining cropland. Also included in this category are carbon stock changes in organic soils on land converted to cropland and emissions of carbon dioxide from the application of crushed limestone and dolomite to all managed lands. The estimation methods used for these estimates are consistent with the Revised 1996 IPCC Guidelines and the LULUCF GPG.

Land Converted to Cropland

Carbon stock changes for this category include only carbon stock changes in mineral soils. Carbon stock changes in organic soils and emissions of carbon dioxide from the application of crushed limestone and dolomite that occur on land converted to cropland, as indicated above, are reported in the category of cropland

Table 33. Net Carbon Dioxide Sequestration from U.S. Land-Use Change and Forestry, 1990 and 1998-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Component	1990	1998	1999	2000	2001	2002	2003	2004
Forest Land Remaining Forest Land: Changes in Forest Carbon Stocks	773.4	618.8	637.9	631.0	634.0	634.6	635.8	637.2
Cropland Remaining Cropland: Changes in Agricultural Soil Carbon Stocks and Liming Emissions	33.1	24.6	24.6	26.1	27.8	27.5	28.7	28.9
Land Converted to Cropland: Changes in Agricultural Soil Carbon Stocks	-1.5	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Grassland Remaining Grassland: Changes in Agricultural Soil Carbon Stocks	4.5	-7.5	-7.5	-7.4	-7.4	-7.4	-7.3	-7.3
Land Converted to Grassland: Changes in Agricultural Soil Carbon Stocks	17.6	21.1	21.1	21.1	21.1	21.1	21.1	21.1
Settlements Remaining Settlements	83.2	84.2	86.8	85.9	89.7	89.9	93.8	97.3
Urban Trees	*58.7*	*73.3*	*77.0*	*77.0*	*80.7*	*80.7*	*84.3*	*88.0*
Landfilled Yard Trimmings and Food Scraps	*24.5*	*10.9*	*9.8*	*8.9*	*9.0*	*9.3*	*9.4*	*9.3*
Total Net Flux	**910.4**	**744.0**	**765.7**	**759.5**	**768.0**	**768.6**	**774.8**	**780.1**

Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenter PublicationsGHGEmissionsUSEmissionsInventory2006.html.

113 The USDA's Forest Inventory and Analysis (FIA) Program provides the information needed to assess forests in the United States. FIADB is the FIA database. Through an annual survey, FIA reports on status and trends in forest area and location. See web site http://fia.fs.fed.us.

114 For each State survey, FORCARB2 (a combination of conversion methods and models) was used to estimate each forest carbon pool.

115 The STATSGO database is a 1:250,000 scale generalized soils database, prepared by the National Resources Conservation Service of the U.S. Department of Agriculture. See web site www.ncgc.nrcs.usda.gov/products/datasets/statsgo.

Methane Emissions From Vegetation: New Findings

For several decades, the conventional view of climate scientists has been that terrestrial vegetation produces methane only under anaerobic conditions, through the action of anaerobic bacteria on organic matter in rice paddies and wetlands; however, recent studies by Frank Keppler of the Max Planck Institute for Nuclear Physics, along with researchers at other European institutions, indicate that vegetation can emit methane under aerobic conditions.[a] This discovery has prompted a lively discussion both among scientists and in the press, given the importance of methane as a greenhouse gas of concern (methane is second in importance only to carbon dioxide, with 23 times its global warming potential) and the role of afforestation and reforestation in national and international efforts to mitigate emissions of greenhouse gases.

Keppler and his fellow investigators measured methane emissions from vegetation exposed to methane-free air, using intact plants in plexiglass chambers and freshly collected tree and grass leaves in sealed vials. To rule out a possible role of anaerobic bacteria, gamma radiation was used to kill any such bacteria in the samples. First-estimate extrapolations from laboratory measurements to a global scale, based on net primary productivity, produced an estimate of annual methane emissions from terrestrial vegetation between 62 and 236 MMT. In comparison, previous estimates of global methane emissions from all known sources (wetlands, animals, rice cultivation, biomass burning, and fossil fuel production) have totaled approximately 600 MMT per year. Given the considerable uncertainty associated with methane emissions estimates for those sources, Keppler suggested that up to 50 MMT of methane from vegetation may already be included (erroneously) in some of the previous estimates attributed to sources such as wetlands or rice paddies.

Keppler's estimate of methane emissions from vegetation, extrapolated to the global scale, was then used to estimate annual emissions from various sources, based on type of vegetation, ecosystem, and region. For tropical forests, the researchers estimated mean annual methane emissions of 78.2 MMT per year, and for tropical savannas and grasslands they estimated mean annual emissions of 29.2 MMT per year. The results are in conformity with recent field and satellite measurements, which indicate annual methane emissions in upland zones of the Brazilian Amazon in the range of 4 to 38 MMT[b] and annual emissions in the northern part of the Guyana shield of Venezuela in the range of 30 to 60 MMT for the entire savanna.[c]

Other recent research has compared emissions measured using the SCIAMACHY instrument of the European Space Agency's ENVISAT satellite against modeled data, finding significant discrepancies over tropical forests.[d] The measured values were consistently higher than the modeled values, with a discrepancy of 30 MMT methane per year. Adding the discrepancy to the modeled value of 45 MMT per year yields an estimate of 75 MMT for annual methane emissions from tropical forests, as compared with Keppler's estimate of 78.2 MMT.

The extrapolation of emission rates from laboratory experiments to global emission rates in the study by Keppler was based on the rate of growth of terrestrial vegetation, or "net primary productivity." Other researchers, however, have argued that the use of net primary productivity leads to an overestimate of methane emissions from vegetation, and that estimation methods based on leaf mass and photosynthesis would be more appropriate.[e] Those methods yield global estimates of 10 to 60 MMT methane per year. A similar range, 0 to 46 MMT, has been estimated by researchers using a "top-down" approach based on ice core records.[f]

(continued on page 74)

[a]F. Keppler, J.T.G. Hamilton, M. Braß, and T. Röckmann, "Methane Emissions From Terrestrial Plants Under Aerobic Conditions," *Nature*, Vol. 439 (January 2006), pp. 187-191, web site http://moab.colorado.edu/BRG/Methane.pdf.

[b]J.B. do Carmo, M. Keller, J.D. Dias, P.B. de Camargo, and P. Crill, "A Source of Methane From Upland Forests in the Brazilian Amazon," *Geophysical Research Letters*, Vol. 33, No. 4 (2006), pp. 1-4, web site www.agu.org/pubs/crossref/2006/2005GL025436.shtml.

[c]P. J. Crutzen, E. Sanhueza, and C. A. M. Brenninkmeijer, "Methane Production From Mixed Tropical Savanna and Forest Vegetation in Venezuela," *Atmospheric Chemistry and Physics Discussions*, Vol. 6 (2006), pp. 3093-3097, web site www.copernicus.org/EGU/acp/acpd/6/3093.

[d]C. Frankenberg, J.F. Meirink, M. van Weele, U. Platt, and T. Wagner, "Assessing Methane Emissions From Global Space-Borne Observations," *Science*, Vol. 308, No. 5724 (2005), pp. 1010-1014, web site www.sciencemag.org/cgi/content/abstract/1106644.

[e]M.U.F. Kirschbaum, D. Bruhn, D.M. Etheridge, J.R. Evans, G.D. Farquhar, R.M. Gifford, K.I. Paul, and A.J. Winters, "A Comment on the Quantitative Significance of Aerobic Methane Release by Plants," *Functional Plant Biology*, Vol. 33, No. 6 (2006), pp. 521-530, web site www.publish.csiro.au/nid/102/paper/FP06051.htm.

[f]D.F. Ferretti, J.B. Miller, J.W.C. White, K.R. Lassey, D.C. Lowe, and D.M. Etheridge, "Stable Isotopes Provide Revised Global Limits of Aerobic Methane Emissions from Plants," *Atmospheric Chemistry and Physics Discussions*, Vol. 6 (2006), pp. 5867-5875, web site www.copernicus.org/EGU/acp/acpd/6/5867.

Methane Emissions From Vegetation: New Findings (Continued)

When limits are placed on emissions of greenhouse gases—either through binding international commitments such as the Kyoto Protocol or through voluntary programs, such as those being instituted at the State and Federal levels in the United States—knowing how much methane is emitted from various sources will be of obvious importance. In particular, if tree planting is proposed as a means of mitigating greenhouse gas emissions through carbon sequestration, the possibility that the same trees could be a major source of methane emissions would affect calculations of their potential benefits, depending on the balance between carbon dioxide sequestration and methane emissions.

Writing in the same issue of *Nature* that contains the original article by Keppler et al., David Lowe hinted at some of the policy implications, suggesting that trees in reforestation projects might increase greenhouse warming through methane emissions.[g] On the other hand, researchers in Australia have reported that, based on their own extrapolations of methane emissions from vegetation at the global level, the likely increase in methane emissions as a result of tree planting would offset only a small part (estimated at 0.1 to 1.1 percent) of the benefit resulting from increased carbon sequestration.[h]

[g] D. Lowe, "Global Change: A Green Source of Surprise," *Nature*, Vol. 439 (2006), pp. 148-149, web site www.nature.com/nature/journal/v439/n7073/edsumm/e060112-09.html.
[h] M.U.F. Kirschbaum et al., "A Comment on the Quantitative Significance of Aerobic Methane Release by Plants," *Functional Plant Biology*, Vol. 33, No. 6 (2006), pp. 521-530, web site www.publish.csiro.au/nid/102/paper/FP06051.htm.

remaining cropland. This adjustment is made because of the difficulty in separating the land-use components (cropland remaining cropland) from the land-use change components (land converted to cropland) of the carbon stock changes.

Grassland Remaining Grassland

This category includes carbon stock changes in both organic and mineral soils. It also includes changes in organic soils on land converted to grassland, because it is not possible to separate them from carbon stock changes in organic soils on existing grassland. Emissions of carbon dioxide from the application of crushed limestone and dolomite to grassland remaining grassland are included in the category of cropland remaining cropland because of the difficulty in separating the land-use and land-use change components of the carbon stock changes.

Land Converted to Grassland

This category includes carbon stock changes in mineral soils on land recently converted to grassland. Changes in organic soil carbon stocks and carbon dioxide emissions from the application of crushed limestone and dolomite to land converted to grassland are reported in the category of cropland remaining cropland because of the difficulty in separating the land-use and land-use change components of the carbon stock changes.

Settlements Remaining Settlements

This category includes carbon stock changes from settlements remaining settlements and from land converted to settlements. Carbon stock changes from settled lands include stock changes in urban trees as well as landfilled yard trimmings and food scraps. Stock changes in urban trees were estimated on the basis of field measurements and data on national urban tree cover, using a methodology consistent with the LULUCF GPG to estimate carbon flux. Carbon stocks in landfilled yard trimmings and food scraps were estimated by determining the fraction of carbon stocks from earlier years that had decayed by 2004. Emissions of carbon dioxide emissions from the application of crushed limestone and dolomite to settled lands were reported in the category of cropland remaining cropland. Nitrous oxide emissions from nitrogen applied to turf grass were estimated by assuming that such applications represented 10 percent of all synthetic fertilizer used in the United States.

Land-Use Change and Forestry Carbon Sequestration

The EPA's estimates for carbon sequestration from land-use change and forestry in 2004 include the following categories: (1) changes in forest carbon stocks for forest land remaining forest land (637.2 $MMTCO_2e$ or 82 percent of the total); (2) changes in agricultural soil carbon stocks for cropland remaining cropland (28.9 $MMTCO_2e$ or 3.7 percent of the total); (3) changes in agricultural soil carbon stocks for land converted to cropland (2.8 $MMTCO_2e$ or less than 0.5 percent of the total); (4) changes in agricultural soil carbon stocks for grassland remaining grassland (-7.3 $MMTCO_2e$ or -0.9 percent of the total[116]); (5) changes in agricultural soil carbon stocks for land converted to grassland (21.1

[116] Negative sequestration numbers indicate an emission source rather than an emission sink.

$MMTCO_2e$ or 2.7 percent of the total); and (6) changes in settlements remaining settlements (97.3 $MMTCO_2e$ or 12 percent of the total, including 88.0 $MMTCO_2e$ from urban trees and 9.3 $MMTCO_2e$ from landfilled yard trimmings and food scraps).[117]

Forest Land Remaining Forest Land: Changes in Forest Carbon Stocks

In the United States, the most significant pressures on the amount of carbon sequestered through forest land are land management activities and the continuing effects of past changes in land use. These activities directly affect carbon flux by shifting the amount of carbon accumulated in forest ecosystems.[118] Land management activities affect both the stocks of carbon that can be stored in land-based carbon sinks, such as forests and soils, and the fluxes of carbon between land-based sinks and the atmosphere (see text box below for the most recent global assessment of the world's forests).

The components or "pools" of forest carbon analyzed by the EPA for its most recent inventory include above-ground biomass, below-ground biomass, dead wood, litter, and soil organic carbon. The EPA also assessed harvested wood products in use, and harvested wood products in landfills. As a result of natural biogeochemical processes occurring in forests, as well as anthropogenic activities, carbon is constantly cycling through these components and between the forest and the atmosphere. The net change in overall forest carbon may not always be equal to the net flux between forests and the atmosphere, because timber harvests may not necessarily result in an instant return of carbon to the atmosphere. Timber harvesting transfers carbon from one of the five "forest carbon pools" to one of the two "wood products carbon pools." Once carbon is transferred to a product pool, it is emitted over time as carbon dioxide or methane as the product decays or is combusted. Emission rates vary significantly, depending on the type of product pool that houses the carbon.[119]

In the United States, enhanced forest management, regeneration of formerly cleared forest areas, and timber harvesting have resulted in net annual sequestration of carbon throughout the past decade. Since the 1920s, deforestation for agricultural purposes has become a

Global Forest Resources Assessment 2005

The Food and Agriculture Organization of the United Nations (FAO) is the main intergovernmental source of data on global forests. FAO's global forest assessments date back to 1948, with the most recent assessment—*Global Forest Resources Assessment 2005*—published in 2005. The FAO's 2000 assessment[a] was the first to include a uniform definition of forests for all regions of the world—that is, areas with at least 10 percent of canopy cover (excluding stands of trees primarily used for agricultural production). The current report estimates the world's forested area in 2005 at approximately 4 billion hectares or 30 percent of the Earth's total land area.

The 2005 report points out that, while the rate of deforestation (mainly through conversion to cropland) continues at the high rate of about 13 million hectares per year, average net annual losses of forest have fallen from 8.9 million hectares per year over the period 1990-2000 to 7.3 million hectares per year over the period 2000-2005. Forest planting, landscape restoration, and the natural expansion of forests have significantly reduced the net loss of forest area.[b]

The largest reported net loss of forest land from 2000 to 2005 was in South America, with 4.3 million hectares lost per year, followed by Africa, which lost 4.0 million hectares annually. North and Central America and Oceania each had a net loss of about 350,000 hectares per year, while Asia reported a net gain of 1 million hectares per year from 2000 to 2005, primarily from large-scale afforestation in China. Forest areas in Europe continued to expand, although at a slower rate than in the 1990s.

[a]Food and Agriculture Organization of the United Nations, *Global Forest Resources Assessment 2000*, "Executive Summary," web site www.fao.org/DOCREP/004/Y1997E/y1997e05.htm#bm05.

[b]Food and Agriculture Organization of the United Nations, *Global Forest Resources Assessment 2005*, "Executive Summary," web site www.fao.org/docrep/008/a0400e/a0400e00.htm.

[117] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[118] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[119] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), p. 7-4, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

nearly defunct practice. Managed growth practices have become common in eastern forests since the early 1950s, almost doubling their biomass density.[120] In the 1970s and 1980s, federally sponsored tree planting and soil conservation programs were embraced. These programs led to the reforestation of formerly harvested lands, improvement in timber management activities, soil erosion abatement, and the conversion of cropland to forests. Forest harvests have also affected carbon sequestration. The majority of harvested timber in the United States is used in wood products. The bulk of the discarded wood products is landfilled, and thus large quantities of the harvested carbon are relocated to long-term storage pools rather than to the atmosphere. The combined size of the long-term storage pools has increased over the past century.[121]

According to the EPA, carbon sequestration in U.S. forests and harvested wood pools totaled 637.2 MMTCO_2e in 2004 (Table 34). From 1990 to 2004, U.S. forests and harvested wood pools accounted for an average annual net sequestration of 627.0 MMTCO_2e, resulting from domestic forest growth and increases in forested land area; however, there was a decrease of approximately 18 percent in annual sequestration over the same period.[122]

The overall decline of carbon sequestration in forests and harvested wood pools resulted from a 25-percent reduction in the level of sequestration in the forest carbon pool (420.2 MMTCO_2e in 2004 versus 563.3 MMTCO_2e in 1990). The reduction in the sequestration rate for forest carbon pools can be attributed primarily to a reduction in sequestration levels in litter and soil organic carbon. Sequestration in litter declined by 68 percent, from 82.9 MMTCO_2e in 1990 to 26.6 MMTCO_2e in 2004, and sequestration in soil organic carbon declined by 130 percent—that is, soil organic carbon went from being a carbon sink of 33.6 MMTCO_2e in 1990 to an emissions source of 10.1 MMTCO_2e in 2004.

The EPA explains that, because its soil carbon estimates currently assume that soil carbon density depends only on broad forest type, the estimated decrease in annual carbon sequestration depends only on changes in total forest area or changes in forest type.[123] Net forest growth and increasing forest area, particularly before 1997, contributed to rising sequestration; but since 1997, forest land area has remained relatively constant, and the increase in carbon density (per area) has resulted in net forest carbon sequestration. National estimates of forest land are obtained by summing State surveys for the

Table 34. Net Carbon Dioxide Sequestration in U.S. Forests and Harvested Wood Pools, 1990 and 1998-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Carbon Pool	1990	1998	1999	2000	2001	2002	2003	2004
Forests	**563.3**	**412.7**	**423.2**	**420.2**	**420.2**	**420.2**	**420.2**	**420.2**
Above-Ground Biomass	338.5	287.5	306.6	310.3	310.3	310.3	310.3	310.3
Below-Ground Biomass	64.8	55.1	59.5	60.3	60.3	60.3	60.3	60.3
Dead Wood	43.5	41.6	35.5	33.2	33.2	33.2	33.2	33.2
Litter	82.9	12.4	24.9	26.6	26.6	26.6	26.6	26.6
Soil Organic Carbon	33.6	16.0	-3.2	-10.1	-10.1	-10.1	-10.1	-10.1
Harvested Wood	**210.1**	**206.1**	**214.7**	**210.8**	**213.8**	**214.4**	**215.6**	**217.0**
Wood Products	47.6	51.9	61.5	58.7	59.0	59.2	60.4	60.8
Landfilled Wood	162.4	154.2	153.1	152.1	154.8	155.3	155.1	156.2
Total	**773.4**	**618.8**	**637.9**	**631.0**	**634.0**	**634.6**	**635.8**	**637.2**

Notes: The sums of the annual net stock changes in this table (shown in the “Total” row) represent estimates of the actual net flux between the total forest carbon pool and the atmosphere. Forest estimates are based on periodic measurements; harvested wood estimates are based on annual surveys and models. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[120] The term “biomass density” refers to the mass of vegetation per unit area. It is usually measured on a dry-weight basis. Dry biomass is 50 percent carbon by weight.

[121] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), p. 7-5, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[122] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), p. 7-5, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[123] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), p. 7-5, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

conterminous United States. Because the State surveys are not completed each year, interpolation between data points is used to provide estimates for years without surveys.

Overall annual sequestration levels in harvested wood carbon stocks increased slightly from 1990 to 2004. The trend in net sequestration amounts has been generally upward, from 210.1 $MMTCO_2e$ in 1990 to 217.0 $MMTCO_2e$ in 2004 (Table 34). Annual sequestration levels in landfilled wood declined from 162.4 $MMTCO_2e$ in 1990 to 156.2 $MMTCO_2e$ in 2004, but that decline was offset by an increase in carbon sequestration in harvested wood products, from 47.6 $MMTCO_2e$ in 1990 to 60.8 $MMTCO_2e$ in 2004.

The EPA has estimated carbon stocks in wood products in use and in landfills from 1910 onward, based on USDA Forest Service historical data and analyses using the North American Pulp and Paper (NAPAP) model,[124] the Timber Assessment Market Model (TAMM),[125] and the Aggregate Timberland Assessment System (ATLAS) model.[126] Carbon decay in harvested wood was analyzed by the EPA for the period 1910 through 2004, using data on annual wood and paper production. The analysis included changes in carbon stocks in wood products, changes in carbon in landfills, and the amount of carbon (carbon dioxide and methane) emitted to the atmosphere both with and without energy recovery. The EPA also followed the "production approach"; that is, carbon stored in imported wood products was not counted, but carbon stored in exports was counted, including logs processed in other countries.[127]

Cropland Remaining Cropland: Changes in Agricultural Soil Carbon Stocks

The amount of organic carbon in soils depends on the balance between the addition of organic material and the loss of carbon through decomposition. The quantity and quality of organic matter within soils, as well as decomposition rates, are determined by the interaction of climate, soil properties, and land use. Agricultural practices—including clearing, drainage, tillage, planting, grazing, crop residue management, fertilization, and flooding—can alter organic matter inputs and decomposition, causing a net flux of carbon to or from soils.

The IPCC methodology, which is used by the EPA to estimate the net flux from agricultural (cropland) soils, is divided into three categories of land use and land management activities (Table 35): (1) agricultural land use and land management activities on mineral soils;[128] (2) agricultural land use and land management activities on organic soils;[129] and (3) liming of soils. Of the three activities, the use and management of mineral soils is estimated to be the most significant contributor to total carbon sequestration from 1990 through 2004. Sequestration in mineral soils in 2004 was estimated to be 63.2 $MMTCO_2e$, and emissions from organic soils and liming were estimated at 30.3 and 4.0 $MMTCO_2e$, respectively. Together, these three activities resulted in a net 28.9 $MMTCO_2e$ sequestered through agricultural soils in 2004, or 12 percent below the 1990 carbon sequestration level of 33.0 $MMTCO_2e$.[130]

Land Converted to Cropland

The EPA for the first time provided an estimate of carbon stock changes for land converted to cropland in its 2004 data release. The estimate covers only mineral soils, with estimates for organic soil and liming on land converted to cropland being included in the category of cropland remaining cropland, because it was not possible to subdivide those estimates by land use. Land use and management of land converted to cropland led to carbon losses (emissions) in the early 1990s. In 1990, for example, land converted to cropland led to net emissions of 1.5 $MMTCO_2e$ (Table 33). The trend has since

[124] P.J. Ince, *Recycling and Long-Range Timber Outlook*, USDA Forest Service General Technical Report RM-242 (Fort Collins, CO, February 1994).

[125] U.S. Department of Agriculture, Forest Service, *An Analysis of the Timber Situation in the United States: 1952 to 2050*, General Technical Report PNW-GTR-560 (Portland, OR, February 2003), web site www.fs.fed.us/pnw/pubs/gtr560.

[126] J.R. Mills and J.C. Kincaid, *The Aggregate Timberland Assessment System–ATLAS: A Comprehensive Timber Projection Model*, USDA Forest Service General Technical Report PNW-281 (Portland, OR, June 1992), web site www.fs.fed.us/pnw/pubs/pnw_gtr281.pdf.

[127] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), pp. 7-7–7-8, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG EmissionsUSEmissionsInventory 2006.html.

[128] Mineral soils are soils consisting predominantly of, and having their properties determined predominantly by, mineral matter. They usually contain less than 200 grams of organic carbon per kilogram of soil (less than 120 to 180 grams per kilogram if saturated with water) but may contain an organic surface layer up to 30 centimeters thick.

[129] Organic soils are soils that, when saturated with water, have 174 grams or more of organic carbon per kilogram of soil if the mineral fraction has 500 grams per kilogram or more of clay, or 116 grams per kilogram organic carbon if the mineral fraction has no clay, or has proportional intermediate contents. If the soil is never saturated with water, organic soils have 203 or more grams of organic carbon per kilogram.

[130] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2006.html.

been reversed, and in 2004 land converted to cropland resulted in net carbon sequestration equivalent to 2.8 $MMTCO_2e$, primarily in the intermountain west and central areas of the country.[131]

Grassland Remaining Grassland

Carbon stock changes for this category—also provided for the first time by the EPA in its 2004 data release—include changes in soil carbon storage resulting from agricultural land-use and management activities on mineral and organic soils. Carbon dioxide emissions due to the liming of soils on grassland remaining grassland are not included in this category but instead are placed in the category of cropland remaining cropland, because it is not possible to separate the emissions by land-use categories. In 2004, this category accounted for emissions of 7.3 $MMTCO_2e$, including 4.6 $MMTCO_2e$ from organic soils and 2.7 $MMTCO_2e$ from mineral soils (Table 36). In 1990, this category sequestered 4.5 $MMTCO_2e$, based on net sequestration of 8.8 $MMTCO_2e$ in mineral soils and emissions of 4.3 $MMTCO_2e$ from organic soils. The change in this category to a source of emissions is the result of reduced rates of carbon sequestration in mineral soils in the southern United States and increased emissions from the drainage of organic soils in other regions.[132]

Land Converted to Grassland

Estimates of carbon stock changes for land converted to grassland were also provided for the first time by the EPA in its 2004 data release. The estimates cover only mineral soils. Estimates of changes in organic soil carbon stocks for this category are included in the estimates for the category of grassland remaining grassland, and emissions from liming of soils for this category are included in those reported for the category of cropland remaining cropland, because it was not possible to subdivide the estimates by land use. Net soil carbon storage for this category increased from 17.6 $MMTCO_2e$ in 1990 to 21.1 $MMTCO_2e$ in 2004 (Table 33). The upswing was

Table 35. Net Carbon Dioxide Sequestration in U.S. Cropland Remaining Cropland, 1990 and 1998-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990	1998	1999	2000	2001	2002	2003	2004
Mineral Soils	67.6[a]	59.6[b]	59.3[b]	60.7[b]	62.5[b]	62.8[b]	62.7[b]	63.2[b]
Organic Soils	-29.9[a]	-30.3[b]	-30.3[b]	-30.3[b]	-30.3[b]	-30.3[b]	-30.3[b]	-30.3[b]
Liming of Soils	-4.7[a]	-4.7[a]	-4.5[a]	-4.3[a]	-4.4[a]	-5.0[a]	-3.7[a]	-4.0[b]
Total	**33.0[a]**	**24.6[b]**	**24.6[b]**	**26.1[b]**	**27.8[b]**	**27.5[b]**	**28.7[b]**	**28.9[b]**

[a]Estimates based on historical data.
[b]Estimates based on a combination of historical data and projections.
Note: Negative values indicate net emissions.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

Table 36. Net Carbon Dioxide Sequestration in U.S. Grassland Remaining Grassland, 1990 and 1998-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990	1998	1999	2000	2001	2002	2003	2004
Mineral Soils	8.8[c]	-2.9[d]	-2.9[d]	-2.9[d]	-2.8[d]	-2.8[d]	-2.7[d]	-2.7[d]
Organic Soils[a]	-4.3[c]	-4.6[d]	-4.6[d]	-4.6[d]	-4.6[d]	-4.6[d]	-4.6[d]	-4.6[d]
Liming of Soils[b]	—	—	—	—	—	—	—	—
Total	**4.5[c]**	**-7.5[d]**	**-7.5[d]**	**-7.4[d]**	**-7.4[d]**	**-7.4[d]**	**-7.3[d]**	**-7.3[d]**

[a]Includes emissions resulting from drainage of organic soils in land converted to grassland.
[b]Reported in Table 35 (cropland remaining cropland).
[c]Estimates based on historical data.
[d]Estimates based on a combination of historical data and projections.
Note: Negative values indicate net emissions.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[131] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), p. 7-26, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[132] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), p. 7-29, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

the result of increased acreage of cropland converted to pasture, primarily in the Southeast and Northwest.[133]

Settlements Remaining Settlements

Carbon stock changes for this category include carbon stock changes for urban trees and for landfilled yard trimmings and food scraps. Carbon sequestration for this category increased by 17 percent, from 83.2 $MMTCO_2e$ in 1990 to 97.3 $MMTCO_2e$ in 2004 (Table 33), with significant increases in carbon storage by urban trees more than offsetting declines in net carbon storage in landfilled yard trimmings and food scraps.

Changes in Urban Tree Carbon Stocks

Urban forests make up a considerable portion of the total tree canopy cover in the United States. Urban areas, which cover 4.4 percent of the continental United States, account for approximately 3 percent of total tree cover in the United States. The EPA's carbon sequestration estimates for urban trees are derived from estimates by Nowak and Crane,[134] based on data collected from 1989 through 1999 in 10 U.S. cities. Currently, annual changes in sequestration estimates are based solely on changes in total U.S. urban area. Net carbon dioxide sequestration by urban trees increased by 50 percent, to 88.0 $MMTCO_2e$ in 2004 from 58.7 $MMTCO_2e$ in 1990 (Table 33), primarily as a result of increases in urban land area.[135]

Changes in Landfilled Yard Trimming and Food Scrap Carbon Stocks

Carbon stored in landfilled yard trimmings and food scraps can remain sequestered indefinitely. In the United States, yard trimmings (grass clippings, leaves, and branches) and food scraps make up a considerable portion of the municipal waste stream, and significant amounts of the yard trimmings and food scraps collected are discarded in landfills. Both the amount collected annually and the percentage that is landfilled have declined over the past decade. Net carbon dioxide sequestration from landfilled yard trimmings and food scraps has declined accordingly, to 9.3 $MMTCO_2e$ in 2004 from 24.5 $MMTCO_2e$ in 1990—a reduction of 62 percent (Table 37).

Since 1990, municipal policies limiting pickup and disposal have led to an 18-percent decrease in yard trimmings collected. In addition, composting of yard trimmings in municipal facilities has increased significantly, reducing the percentage of collected yard trimmings discarded in landfills from 72 percent in 1990 to 35 percent in 2004. In contrast, the percentage of food scraps disposed of in landfills has decreased only slightly, from 81 percent in 1990 to 78 percent in 2003.[136] The EPA's methodology for estimating carbon storage relies on a life-cycle analysis of greenhouse gas emissions and sinks associated with solid waste management.[137]

Table 37. Net Carbon Dioxide Sequestration from Landfilled Yard Trimmings and Food Scraps, 1990 and 1998-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990	1998	1999	2000	2001	2002	2003	2004
Yard Trimmings	**21.7**	**8.0**	**6.9**	**5.6**	**5.8**	**6.1**	**6.3**	**6.4**
Grass	2.4	0.8	0.6	0.5	0.6	0.6	0.7	0.7
Leaves	9.8	3.6	3.0	2.5	2.5	2.6	2.7	2.8
Branches	9.6	3.7	3.2	2.7	2.7	2.8	2.9	2.9
Food Scraps	**2.8**	**2.9**	**2.9**	**3.2**	**3.2**	**3.2**	**3.1**	**2.9**
Total	**24.5**	**10.9**	**9.8**	**8.9**	**9.0**	**9.3**	**9.4**	**9.3**

Note: Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenter PublicationsGHGEmissionsUSEmissionsInventory2006.html.

[133] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), p. 7-34, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG EmissionsUSEmissionsInventory2006.html.

[134] D.J. Nowak and D.E. Crane, "Carbon Storage and Sequestration by Urban Trees in the United States," *Environmental Pollution*, Vol. 116, No. 3 (2002), pp. 381-389, web site www.uvm.edu/~bwemple/geog242/pdfs/nowak_crane_2002.pdf.

[135] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-04-002 (Washington, DC, April 2006), p. 7-42, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG EmissionsUSEmissionsInventory2005.html.

[136] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), p. 7-37, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG EmissionsUSEmissionsInventory2006.html.

[137] U.S. Environmental Protection Agency, *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*, 2nd Edition, EPA530-R-02-006 (Washington, DC, May 2002), web site www.epa.gov/epaoswer/non-hw/muncpl/ghg/ghg.htm.

Land Use and International Climate Change Negotiations

In past international negotiations on climate change, the United States and many other countries have maintained that the inclusion of LULUCF activities in a binding agreement that limits greenhouse gas emissions is of the utmost importance; however, issues of whether and how terrestrial carbon sequestration could be accepted for meeting various commitments and targets have remained subjects of complex and difficult international negotiations.

Many of the countries involved in climate change negotiations have agreed that implementation of LULUCF activities under an international climate change agreement may be complicated by a lack of clear definitions of "reforestation" and "forest." Further, implementation may be hindered by the lack of effective accounting rules. According to research published by the Pew Center on Global Climate Change,[138] implementation of LULUCF provisions in an international climate change agreement raises many issues, such as:

- What is a direct human-induced activity?
- What is a forest and what is reforestation?
- How will the issues of uncertainty and verifiability be addressed?
- How will the issues of (non) permanence and leakage be addressed?
- Which activities beyond afforestation, reforestation, and deforestation (ARD), if any, should be included, and what accounting rules should apply?
- Which carbon pools and which greenhouse gases should be considered?

Uncertainties related to data issues have also slowed international negotiations on climate change.

The Ninth Session of the Conference of the Parties to the UN Framework Convention on Climate Change (COP-9 of the UNFCCC) was held in Milan, Italy, in December 2003. The parties agreed on some of the rules for carbon sequestration projects under the Clean Development Mechanism (CDM), but the issue of how to treat the non-permanence of carbon sinks projects remained unresolved. Delegates at COP-9 decided to limit the duration of credits generated from carbon sequestration projects and addressed the topics of additionality, leakage, uncertainties, and socioeconomic and environmental impacts.[139]

A year later in Buenos Aires, Argentina, delegates at the Tenth Conference of the Parties (COP-10 of the UNFCCC) did address the issue of small-scale afforestation and reforestation project activities under the CDM. The following decisions were made at COP-10:[140]

- Adopt simplified modalities and procedures for small-scale afforestation and reforestation project activities in the first commitment period.
- Limit the designation of small-scale afforestation and reforestation projects to those with net anthropogenic greenhouse gas removals by sinks that are less than 8,000 metric tons carbon dioxide equivalent per year. For projects that result in greenhouse gas removals of more than this quantity, the excess would be ineligible for temporary or long-term certified emissions reductions.
- Exclude funds obtained through small-scale project activities from the share of proceeds to be used to assist developing countries particularly vulnerable to the adverse impacts of climate change. Such countries shall be entitled to a reduced level of the non-reimbursable fee for requesting registration and a reduced rate of the proceeds to cover administrative expenses of the CDM.

In 2005, at the Eleventh Conference of the Parties (COP-11 of the UNFCCC) and the first conference serving as the Meeting of the Parties (MOP) to the Kyoto Protocol, delegates agreed to a set of IPCC Principles, Rules, and Guidelines governing LULUCF activities,[141] such as:

- Carbon stocks must be excluded from greenhouse gas accounting.
- Accounting for LULUCF activities does not imply a transfer of commitments to a future commitment period.
- Reversal of any removal due to LULUCF activities must be accounted for at the appropriate time.

[138] G. Marland and B. Schlamadinger, *Land Use and Global Climate Change: Forests, Land Management, and the Kyoto Protocol* (Arlington, VA: Pew Center on Global Climate Change, June 2000), p. 5, web site www.pewclimate.org/docUploads/land_use.pdf.

[139] Pew Center on Global Climate Change, "Ninth Session of the Conference of the Parties to the UN Framework Convention on Climate Change" (Milan, Italy, December 1-12, 2003), web site www.pewclimate.org/what_s_being_done/in_the_world/cop9/index.cfm.

[140] International Institute for Sustainable Development, "Summary of the Tenth Conference of the Parties to the UN Framework Convention on Climate Change: 6-18 December 2004," *Earth Negotiations Bulletin*, Vol. 12, No. 260 (December 20, 2004), web site www.iisd.ca/vol12/enb12260e.html.

[141] International Institute for Sustainable Development, "Summary of the Eleventh Conference of the Parties to the UN Framework Convention on Climate Change and First Conference of the Parties Serving as the Meeting of the Parties to the Kyoto Protocol: 28 November – 10 December 2005," *Earth Negotiations Bulletin*, Vol. 12, No. 291 (December 12, 2005), web site www.iisd.ca/vol12/enb12291e.html.

The EPA's most recent inventory report discusses the uncertainty inherent in the methodology used to estimate forest carbon stocks.[142] The estimates of forest carbon in live biomass, dead wood, and litter are based on USDA forest survey data for the conterminous United States, because no survey data are available for Alaska, Hawaii, and the U.S. Territories. The survey data are statistical samples designed to represent vast areas of land. The USDA mandates that the survey data be accurate to within 3 percent, at a confidence level of 67 percent.[143] An analysis of this methodology for the southeastern United States showed that the uncertainty resulted from sampling errors and not from the regression equations used to calculate tree volume (and thus carbon) from survey statistics such as tree height and diameter. The standard errors of 1 to 2 percent for volumes of growing stock in individual States are insignificant; however, those for changes in the volumes of growing stock are much higher, ranging from 12 percent to as much as 139 percent.[144]

Additional uncertainty is associated with the estimates of carbon stocks in other carbon pools, which are based on extrapolations of the relationships among variables in site-specific studies to all forest land. Such extrapolation is needed in the absence of survey data on other carbon pools.[145] The extrapolations bring in uncertainty from modeling errors and conversions between different reporting units. The effect of land-use change and forest management activities (such as harvest) on soil stocks is another large source of uncertainty, with little consensus in the literature.

[142] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2006.html.

[143] That is, at least 67 percent of the samples are within 3 percent of the actual forested areas.

[144] The larger errors were found to be attributable to small actual changes in volumes of growing stock, which when over- or underestimated contributed disproportionately to the standard errors for total changes in the volume of growing stock.

[145] Thus, site-specific relationships among variables are used to create models or regression equations, which are then applied to large forested areas.